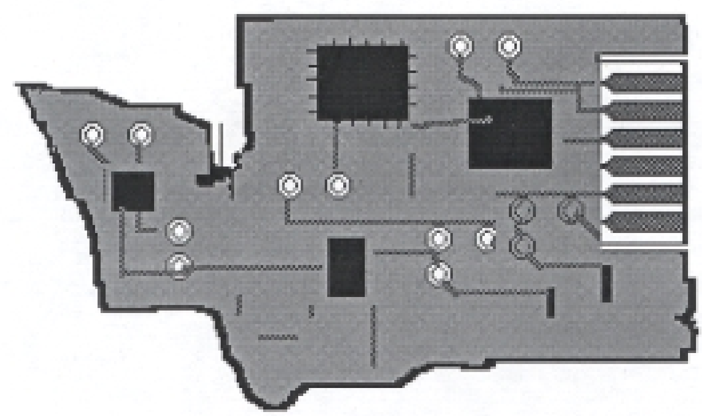

Measuring Pollution Prevention:

Analysis of the Printed Circuit Board Fabrication Sector in Washington State

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

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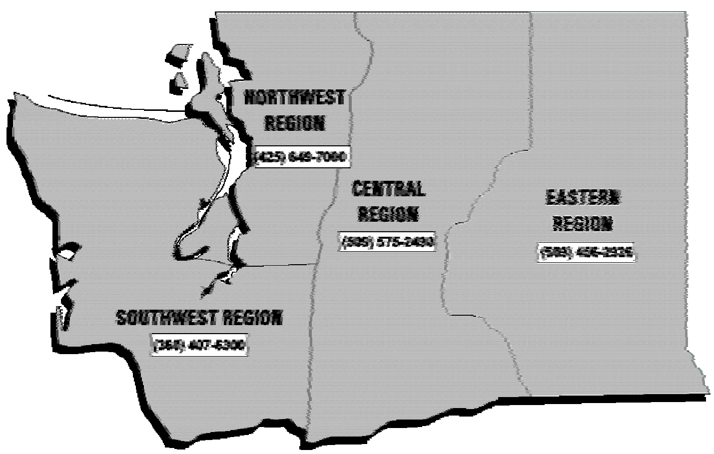

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Analysis of the Printed Circuit Board Fabrication Sector in Washington State

Prepared by:

Washington State Department of Ecology
Hazardous Waste and Toxics Reduction Program

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Executive Summary

In 1995, the Washington State Department of Ecology (Ecology) began to evaluate the implementation status of hazardous waste and hazardous substance pollution prevention planning efforts for three distinct industry classes or sectors. This report describes the evaluation, summarizes the findings, and provides conclusions and recommendations for the printed circuit board fabrication sector.

The sector approach to examining pollution prevention data does the following:

- Provides feedback to the facilities of a defined industry sector on their pollution prevention progress.
- Measures the benefits of pollution prevention implementation.
- Develops a technical assistance strategy to assist the sector in its pollution prevention efforts.

A profile of the wastes, substances, processes, and pollution prevention opportunities of the printed circuit board fabrication (PCBF) sector was developed. This Sector Profile served as the basis for the sector analysis. Information extracted from Pollution Prevention Plans and Annual Progress Reports was placed into a database. Queries of the database were done to identify: general trends within the sector; pollution prevention (P2) opportunities and; processes, substances, and wastes targeted by the PCBF Sector for P2 implementation. Hazardous substances and wastes to be used to measure reductions resulting from implemented pollution prevention opportunities were also identified.

A qualitative analysis of the pollution prevention opportunities identified by the PCBF Sector was conducted and a quantitative analysis of the Sector's hazardous waste generation was done using Annual Dangerous Waste Report data. Specific wastes identified by the Sector Profile were included in this analysis. No analysis of hazardous substance use data was done, because total hazardous substance use is not tracked, making an analysis impossible.

Finally, emerging pollution prevention opportunities were reviewed. These opportunities were based on discussions with PCBF Sector facilities, proposals submitted to Ecology, information developed through the Sector Profile, and the quantitative analysis, of waste generation data.

Data Analysis

The PCBF Sector in Washington comprises eleven commercial producers, located primarily in, the Puget Sound area. The PCBF business is highly competitive and has been subjected to a heightened degree of regulatory scrutiny (focusing on wastewater discharge).

Through P2 planning, the PCBF Sector facilities identified a total of 408 pollution prevention opportunities, of which:

- Fifty-one percent were implemented prior to the planning process.
- Ninety-one percent have been implemented, selected for implementation, or are under further study.
- Nine percent have been rejected.

Opportunity status was ranked by number of P2 opportunities to determine the Sector's resource allocation. That ranking is as follows:

1.	Opportunities implemented prior to planning	206
2.	Opportunities selected for implementation	75
3.	Opportunities under further study	62
4.	Opportunities rejected	37
5.	Opportunities implemented since planning was conducted	28

Waste reduction efforts emphasized rinsing and wastewater treatment, process controls, and management of spent process baths. Substance use reduction emphasized drag-out reduction techniques, process controls, alternatives to electroless plating, and reclamation of spent baths.

While the majority of the P2 opportunities identified by the Sector have been implemented or selected for implementation, significant opportunities for further waste reduction and technical assistance still exist.

Sector Profile

The Sector Profile illustrates the PCBF Sector's pollution prevention standard and technical assistance needs. In addition, it identifies specific hazardous substances and wastes to be tracked as indicators of overall reductions occurring from implemented P2 opportunities.

The Sector's priorities for P2 opportunities implemented prior to planning, implemented during planning, and selected for implementation are:

Wastes:	Wastewater, wastewater sludge (FO06), sulfuric acid, and nitric acid
Substances:	Nitric acid and sulfuric acid, sodium hydroxide and lead
Processes:	Wastewater treatment, develop/etch/strip, electroless and electroplating
Opportunities:	Reduce water use, extend bath life, reduce nitric acid strip, and electrolytic recovery

PCBF facilities can use this list to compare and focus their pollution prevention efforts to ensure they are as competitive as their peers on the pollution prevention front. This list also directs Ecology's technical assistance efforts when working with PCBF facilities to help assure a level playing field.

In addition, these targeted substances and waste streams should make it easier for Ecology to determine if reductions have occurred as a result of pollution prevention efforts.

The Sector's focus for opportunities that were rejected or are under further study are:

Wastes:	Wastewater, wastewater sludge (FO06), and spent etchant
Substances:	Etchant and sulfuric acid
Processes:	Wastewater treatment, develop/etch/strip, and electroplating
Opportunities:	Install sludge dryer, on-site regeneration of spent etchant, evaluate alternative technology to electroless plating

These are areas where Sector facilities have not had much success, and where Ecology needs to direct its future technical assistance efforts.

From 1991 to 1994 the PCBF Sector has:

- Increased total waste generation-excluding wastewater, and after normalization for changes in production.
- Decreased generation of extremely hazardous wastes.
- Increased generation of less toxic dangerous wastes.
- Decreased generation of wastes targeted by pollution prevention opportunities-wastewater, wastewater sludge, spent etchant, and nitric and sulfuric acids.

The cause of the increase in total waste generation is not clearly understood. Possible causes include: increased emphasis on meeting deliveries and customer specifications, incomplete implementation of pollution prevention opportunities, reduced emphasis on manufacturing costs during a time of industry growth, and improved reporting of waste generation.

Recently, several new P2 opportunities have emerged focusing on wastewater, wastewater treatment sludge, and ammoniacal etchant. Of particular interest, Ecology has received proposals which may eliminate wastewater treatment sludge and spent ammoniacal etchant as wastes. Five facilities are performing an analysis of these opportunities to determine their technical and economic feasibility.

Conclusions

- Significant reduction efforts were made by PCBF facilities prior to being required to develop a Pollution Prevention Plan.
- There is a broad acceptance of pollution prevention techniques across most sector facilities.
- The rate of acceptance of opportunities seems to correlate to the focus of regulatory agencies, and the amount of capital investment required - with greater capital investment requiring notably longer implementation periods.
- The Sector rejected a low number of the opportunities identified in Pollution Prevention Plans.
- The Sector still has a number of pollution prevention opportunities to implement.
- There are areas in which PCBF facilities are still seeking answers and may need additional technical assistance.
- The Sector's waste is decreasing in toxicity.
- Specific wastes have been reduced as a result of implementing pollution prevention opportunities.

Recommendations

Sector Facilities are encouraged to:

- Develop a workgroup to focus on both technical and regulatory issues facing them. Ecology could potentially be used to facilitate workgroup sessions. This suggestion is made due to the strong market and regulatory forces that impact the PCBF Sector.
- Utilize Ecology's technical assistance program.

CHAPTER 1
Sector Project Background

This document is a compilation and analysis of information submitted by the fabricators of bare printed circuit boards-Standard Industrial Classification (SIC) Code 3672 -- to the Washington State Department of Ecology (Ecology) in legislatively mandated documents. These documents include Pollution Prevention Plans, Pollution Prevention Annual Progress Reports and Annual Dangerous Waste Reports. In addition to these documents, data is compiled from other Ecology programs and regulatory agencies. Environmental indicators for the printed circuit board fabrication industry are also used.

Legislative History

In 1989, the Washington State Legislature passed House Bill 2390. This law requires facilities to prepare and submit Pollution Prevention Plans to the Department of Ecology. Facilities generating 2,640 lbs. (or more) of hazardous waste per year, and facilities meeting the requirements for EPA's Toxic Release Inventory (TRI) reporting must prepare Pollution Prevention Plans (P2 Plans). The goal of this legislation is to reduce hazardous waste generation by fifty percent by 1995. Among other legal requirements, the P2 Plans mandate facilities to evaluate all technically feasible opportunities to reduce both the use of hazardous Substances as well as the generation of hazardous waste. The facility then submits an Annual Progress Reports (APRs) to identifying the status and tracking reductions associated with each opportunity. The planning process is administered by Ecology's Hazardous Waste and Toxics Reduction Program (HWTR).

Evolution of the Sector Approach

In 1992, Ecology developed a Long Term Technical Assistance (LTTA) strategy. The purpose of the LTTA strategy was to:

- Introduce pollution prevention as a regulatory and management priority on equal footing with product quality and customer service.

- Demonstrate returns on investment for pollution prevention efforts (NOT limited to capital projects).

- Act as a clearinghouse for available information.

- Perform on-site technical and implementation assistance.

It was hoped behavioral change would be initiated by introducing pollution prevention in this manner. If this were the case, then its effects should be seen through development and implementation of P2 Plans.

In 1995, HWTR began to evaluate the implementation status of pollution prevention planning efforts in three industry classes or sectors: electroplating, electronics, and fiberglass reinforced plastics manufacturing. The sector approach does the following:

- Provides feedback to facilities on pollution prevention progress on both a statewide sector basis and on an individual facility basis.
- Measures the benefits of pollution prevention implementation.
- Develops a technical assistance strategy to assist industries with their pollution prevention effort.

Objectives of the Sector Approach

The HWTR management initiated the sector approach in March of 1995. Specific goals for the approach were established at the outset. The scope and objectives evolved as the project developed.

The original purposes of the sector analysis were to:

- Extract the maximum "generic" information from Pollution Prevention Plans and APRs.
- Use this information to benchmark and develop future strategies for select industry sectors. This includes hazardous waste generation and substance use, pollution prevention opportunity data, and economic impact.
- Complete industry/agency workshops and/or publications.
- Support the legislative report to record progress made towards meeting the fifty percent hazardous waste reduction goal.
- Refine technical assistance efforts for industry sectors.

In summary, the objectives of this report are to compile, interpret and present information relating to P2 Plans and environmental practices of the printed circuit board fabrication industry in Washington State. The project scope expanded to include an examination of Ecology's ability to collect, evaluate and use data collected through the pollution prevention planning process. The results of this analysis will be presented in a report to HWTR management.

The PCBF Sector Team

A team was formed for each industry class, from which specific "sectors" were chosen. The Electronics Team is comprised of Toxics Reduction personnel from three regional offices and headquarters. Team members were assigned to the Electronics Team by HWTR Section Managers. Each member was given a time allotment for this project, and assigned specific responsibilities. This information is summarized in Table 1.

Table 1: Electronics Sector Team Members

TEAM MEMBER	REGION	TELEPHONE	PRIMARY RESPONSIBILITY
Miles Kuntz, Project Coordinator	HQ	(360) 407-6748	Establishes timeline, reviews process, handles Legislative Report deliverables, coordinates with management.
David Williams, Team Leader	NWRO	(206) 649-7071	Primary coordinator contact for team, facilitates meetings, establishes timelines, maintains project journal.
Michael Johnson, Tech Lead	SWRO	(360) 407-6338	Chemical engineer experienced in printed circuit board fabrication. Reviews and advises the Team on technical data and issues.
Jeff Phillips	ERO	(509) 456-3162	Plan review, data compilation, ROD data input, quality check.
Elliott Zimmermann	NWRO/ HQ	(206) 649-7072	Plan review, data compilation, Ecology data base development, data analysis.

HQ-Headquarters, NWRO-Northwest Regional Office, SWRO-Southwest Regional Office, ERO-Eastern Regional Office

Individuals on the Sector Team are available to answer questions regarding this report.

The Team's Methodology

The Team set out to develop a profile of the sector. The Sector Profile identifies the priority opportunities, processes, substances and wastes by opportunity status. There are five categories of opportunity status defined as: implemented prior to planning, implemented, selected for implementation, rejected, and under further study. See Figure 2 on page 29.

The profile illustrates two things:

- The Sector's pollution prevention standards. Opportunities, processes, substances and wastes identified under the status "Prior to Planning," "Selected," and "Implemented" tell us what the industry is doing and plans to do. In other words, it establishes an industry pollution prevention standard.

- The Sector's future pollution prevention goals. Opportunities, processes, substances and wastes identified under the status "Rejected" and "Further Study" depict the P2 elements that facilities are going after, but have not had much luck in achieving.

The concept is to create a PCBF Sector Profile by which:

- An individual PCBF facility can compare itself to the sector as a whole.

- Ecology can determine the technical assistance needs of the sector.

- Ecology can enhance the technical assistance it provides to facilities new to P2 planning.

Steps Taken to Conduct Analysis

The Team completed the project in seven steps. Each of these steps are contained in this report as separate sections. Each section contains objectives, descriptions of Team actions taken, and findings. Steps taken to complete this project included:

1. Defining the sector.
2. Providing a general overview of printed circuit board fabrication.
3. Describing the business and regulatory environment.
4. Extracting and storing sector data.
5. Analyzing sector data.
6. Describing further pollution prevention opportunities.
7. Providing conclusions and recommendations.

The team was constrained both by limited resources and time. As a result, the team directed its efforts to compiling information contained in Pollution Prevention Plans, Executive Summaries, Annual Progress reports, Annual Dangerous Waste Reports, Superfund Amendments

Reauthorization Act (SARA) Title III Reports and information from other regulatory agencies. PCBF facility assessments and interviews could not be conducted. Regional staff outside of this project and assigned to targeted facilities were used for supplemental information purposes.

Generation data from Annual Dangerous Waste Reports was used to determine actual waste reduction - in lieu of P2 Plan reduction data. No attempt is made to determine the sector's hazardous substance use reductions or goal achievement. P2 Plan data integrity was a significant concern; hazardous substance use totals were not tracked annually, and goal data changed on an annual basis. This made using these data elements in the quantitative analysis virtually impossible.

CHAPTER 2
The PCBF Sector

Electronics -- SICs 3670 - 3699 -- contains 24 facilities required to prepare P2 Plans in Washington State. The diversity of electronics manufacturing precluded a detailed analysis of plan contents and processes for the entire class. The scope of the investigation was narrowed to printed circuit board fabrication (PCBF) facilities. The Sector had to be defined narrowly in order to create a Sector Profile, and for the findings to have utility, the sector facilities had to have similar processes, substances and wastes. Otherwise, points of comparison and the ability to exchange information will not exist. The selection of the PCBF Sector was based on the following criteria:

- The availability of adequate P2 planning data.
- The quantity of waste generated by the sector.
- The number of facilities in the sector.
- The availability of technical information about the industry.
- The cost of waste treatment and disposal.
- The perceived opportunities for further reductions.

Printed circuit board manufacturing is divided into two broad categories: fabrication and assembly. PCB assembly involves the placement and solder of components onto a fabricated board. Board fabrication, involves chemical intensive manufacturing processes (i.e., electroplating, screen imaging, metal etching). Due to large quantities of hazardous wastes generated and hazardous substances used in PCBF processes, most fabricators were required to prepare Pollution Prevention Plans. A final factor for selecting the PCBF Sector was the adequate and manageable number of facilities in the sector.

Captive printed circuit board shops (those contained in a facility as one of many processes) were excluded from the study. Captive shops were excluded due to the difficulty associated with segregating waste and substance use data of PCBF processes from non-PCBF processes.

The results of these sector analyses are to:

1. Be distributed to industry.
2. Be used to refine pollution prevention efforts.
3. Provide feedback to Ecology on technical assistance efforts thus far.
4. Provide recommendations to Ecology for future technical assistance efforts.

The PCBF Sector is composed of eleven facilities as shown in Table 2. Ten facilities are located in the Northwest Region, and one in the Eastern Region. It is important to note, two of the facilities are no longer in operation; Sanmina of Redmond closed during the planning cycle, and

Key Tronic of Spokane no longer manufactures printed circuit boards. A third facility only entered into the planning process in 1994.

Table 2: PCBF Sector Facility List

WAD #	FACILITY NAME	SITE CITY	ECOLOGY REGION
WAD082506767	Circuits Engineering	Woodinville	NWRO
WAD067156240	Circuit Partners	Issaquah	NWRO
WAD089343354	Circuit Services	Bellevue	NWRO
WAD988474078	Circuit Technology	Redmond	NWRO
IRF319010202	ELDEC Corporation	Lynnwood	NWRO
WAD086258894	Fluke Corporation - Evergreen	Everett	NWRO
WAD048440424	Key Tronic	Spokane	ERO
WAD980978951	Pacific Circuits, Inc.	Redmond	NWRO
WAD130586621	Precision Circuits	Lynnwood	NWRO
WAD980510069	Samnina Corporation	Redmond	NWRO
WAD044038073	Universal Mfg. Corporation	Woodinville	NWRO

General Overview of PCB Fabrication

All of the facilities in the sector manufacture rigid printed circuit boards. Some PCBF facilities specialize in only single- and double-sided product (one or two conductive layers, without conductive inner layers). There was no effort to distinguish multi-layer shops from those which produce only one- and two-sided boards.

Printed circuit boards can be any number of sizes and shapes. Rigid PCBs fall into three basic categories:

- Single-sided--conductive pattern is on one side only and the drilled holes are usually not plated through.

- Double-sided--conductive patterns are on both sides and the drilled holes are generally plated to provide interlayer connection.

- Multi-layer-separate layers of conductive patterns and insulating materials laminated together; internal or external layers are selectively connected via plated through holes.

Printed circuit board fabrication requires the use of process chemicals to clean, selectively add or remove metals and other materials, and photo-image copper fiberglass based material.

The most common PCBF process is the ammoniacal or pattern plati,ng process. This process uses tin or tin-lead plating as etch resist, where the etchant is ammonia-based. In the soldermask over bare copper process (SMOBC) the tin-lead is stripped from the board, solder mask is applied, and the board is immersed in molten solder. Excess solder is removed with hot air.

The approximate process steps for a double-sided board and the chemical products employed are as follows:

1. Prepare or purchase copper clad laminate
2. Drilling
3. Desmear, activation, and electroless plating (permanganate, acids, formaldehyde)
4. Clean copper surface (chemical and/or mechanical)
5. Laminate photoresist or screen image
6. Expose and develop image, if photoimageable (sodium carbonate)
7. Electroplating copper (copper sulfate, sulfuric acid)
8. Sn/Pb plating, rack strip (lead, fluoborates, nitric acid)
9. Etch (ammonium hydroxide, ammonium chloride, cuprous chlorides)
10. Tin-lead strip (for SMOBC) (acids)
11. Apply solder mask (screen or DFSM)
12. Develop/cure solder mask (carbonates)
13. Hot air solder level - HASL (ferric chloride, flux, lead)
14. Screen legend/white ID (solvents)
15. Mechanical fabrication, routing

For brevity, the classes of chemicals and steps listed above are greatly truncated. Several steps are associated with each of the above processes. Very often, several rinsing steps occur between each process step. A great deal of rinsewater has historically been used due to the nature of the chemicals used and cleanliness requirements. The high concentration of heavy metals in rinsewater mandates extensive wastewater treatment systems.

Virtually all of the processes listed above generate waste. Rinsewater effluent, spent process baths (i.e., etchants, plating solutions, and tin-lead strip, resist strip, etc.), and spent cleaning chemicals are the most common sources of hazardous wastes. Most rinsewater effluent, and many of the spent process bath solutions can designate as hazardous waste. These wastes are often treated on-site prior to discharge to a local publicly owned treatment works (POTW). On-site treatment systems produce heavy metal sludges that are transported off-site for disposal or metal reclamation. Some spent process baths are containerized for off-site reclamation, treatment or disposal. Rinsewater, spent etchants and wastewater treatment sludge are the largest waste streams, respectively.

Business and Regulatory Environment from 1991-1994

The research and development of pollution prevention opportunities is potentially impacted by:

1. The business environment-dependent on such factors as capital requirements for changes, market, customer base-directs pollution prevention opportunity assessment and implementation.

2. The regulatory environment through rule development, recorded violations and assessed penalties directs the research and development of pollution prevention opportunities.

3. The type and level of technical assistance also directs the pollution prevention efforts of a facility.

This section will explore these three areas and their impacts on the PCBF Sector.

Business Environment

Bare PCBs are largely a commodity product. Specific market niches, such as quick turn fabrication or small lot sizes, enable smaller companies to compete with commodity-level fabricators. The business is highly cyclical and is currently enjoying a growth cycle. The rising competition and capital intensity has forced a shakeout of the smaller and/or less well financed competitors. In addition, electronic equipment companies making PCBs in-house have often shut down their captive shops and given the business to the merchant producers. This is causing the available market to grow faster than the total market. The PCB fabrication business is generally not dominated by proprietary technology and although several fabrication options exist, the fabrication process is generally standardized.

In addition, this capital intensive business sector is being influenced by the demand for smaller products and increased surface circuit density, both of which drive up the cost of manufacturing. There is also a risk of costs associated with hidden liability for past environmental problems.

Regulatory Environment

The regulatory influence-enforcement and technical assistance-asserted by federal, state and local regulatory agencies, affects the sector's implementation of pollution prevention opportunities. PCBF facilities are subject to environmental regulations primarily by the US Environmental Protection Agency (EPA), the Washington State Department of Ecology, local sewer districts (e.g., METRO) and air pollution control authorities. Each facility has been visited at least once by one of these agencies since 1991.

In the planning period 1991-1994, the sector has been subject to the following environmental regulatory agency actions:

1. **No TRI violations have been found by EPA.**

   Nine of the eleven facilities were required to submit a SARA Title III Report to EPA between 1991 and 1994. Of the two that were not required to report, one was inspected by EPA and found not to be required to file a report. The remaining facility was very similar, so no inspection was done. No violations or penalties have been levied between 1991 and 1994 relating to TRI.

2. **Thirteen calls have been received by Ecology's Emergency Report Tracking System.**

   Ecology's Emergency Report Tracking System (ERTS) received 13 calls relating to PCBF Sector facilities from 1991 through 1994. Five of these calls were referred to HWTR, four to Spill Response, two to the Toxics Cleanup Program, and one to the Water Quality Program. The majority of these calls were in reference to materials/waste handling, or building integrity.

3 **Seven sector facilities were inspected by Ecology's Hazardous Waste compliance unit, none resulting in a financial penalty.**

   HWTR's Compliance staff inspected seven of the 11 sector facilities from 1991 through 1994. Five of these seven sector facilities had violations. No financial penalties resulted from these violations. The most common violations included improper labeling, lack of a training plan, secondary containment, open waste containers, and incidents when copies of manifests were not retained.

4. **Three sector facilities are or have been slated for cleanup measures by Ecology's Toxics Cleanup Program.**

5. **Three sector facilities have notified Ecology of a spill related incident.**

   The Spill Response Program has worked with three of the eleven facilities between 1991 and 1994. Total number of spills occurring was five. Three were PCBF related. Causes of these spills included:

   - A structural fire caused spills of sodium hydroxide and sulfuric acid from melted vats of chemicals within secondary containment inside the building.

   - An allegation that the facility had two separate spills (one of chlorine gas and one of formaldehyde) both of which required evacuating the building, but were not reported by the facility. The facility was allegedly storing chemicals in a non-certified area. This was referred to HWTR.

   - Nitric acid mixed with copper in a bucket resulted in a release for about 3 to 4 minutes. Solution was diluted with water until reaction stopped. All materials cleaned up and no emergency occurred.

6. **Seven sector facilities violated Metro wastewater discharge limits resulting in 44 violations and approximately $200,000 in fines.**

   Metro's primary regulatory concern is wastewater effluent concentration-based limits for discharge to local treatment plants. Low concentration limits challenge traditional wastewater treatment technologies. In addition, the potential fines and other penalties associated with the failure to meet discharge requirements have become more severe. Seven of the 11 sector facilities have been found to have violated their Metro discharge permits. Forty-four violations were found, resulting in fines totaling $203,489 from 1991 through 1994. The majority of the violations were for facilities exceeding limits for copper and lead.

Metro had the most enforcement activity on this sector, based on the number of violations and fines. This suggests future technical assistance efforts be directed to source reduction for wastewater and wastewater treatment. It is widely believed that enforcement can accelerate the adoption of pollution prevention measures. Metro's enforcement may have affected the extent to which pollution prevention practices have been implemented in the Seattle area.

Technical Assistance Efforts

Past technical assistance efforts include a 1992 LTTA strategy that sought to accommodate P2 needs of the sector through site visits, seminars, and maintenance of printed circuit board process and vendor information through the Ecology resource centers. It further proposed publication of success stories and economic models. Due to the lack of an active PCB forum, trade associations were not considered a viable method of disseminating information.

In 1993, an Electronics Industry LTTA Plan Progress Report was written. The principal method for client contact was direct, on-site assistance. Virtually all of the early P2 planning facilities had at least one visit from Ecology. On-site efforts ranged from discussion of water conservation and treatment strategies to teaching a captive facility solder-drossing methods. Telephone assistance was instrumental in P2 Plan preparation, as well as the resolution of technical and regulatory issues. In many cases, this assistance was done in conjunction with local POTWs, Ecology's Water Quality Program, and HWTR.

Currently, several means exist for PCBF facilities to acquire technical assistance. Toxics Reduction staff, Spill Response Teams, and Hazardous Waste inspectors have all participated in technical assistance efforts for the PCBF Sector.

- All eleven sector facilities have been visited by a Toxics Reduction Unit staff member.
- All eleven sector facilities have been contacted by phone-over 100 calls made to facilities.
- All eleven sector facilities have submitted "adequate" P2 Plans and APRs.
- Nine sector facilities have been involved in prior Long Term Technical Assistance (LTTA) efforts by Ecology.

The extent to which technical assistance has facilitated implementation is unknown. Given the relative sophistication of the industry, and the high environmental costs (disposal, penalties, potential liability), it is likely that some pollution prevention techniques would have been broadly adopted regardless of agency influences. The data verifies this assumption. Regulatory assistance, including defining emerging reclamation technologies and proposed rule changes, remains an ongoing effort. Influences from industry groups and non-profit organizations are also notable. The Pacific Northwest Pollution Prevention Research Center has been especially active with the PCBF Sector.

Summary of the Business and Regulatory Environment

The PCBF Sector is a highly regulated, chemical intensive industry. The nature of the manufacturing process insures that most facilities are large quantity generators of hazardous waste. PCBF facilities are subject to categorical wastewater pre-treatment standards, with those facilities using 10,000 gallons of water per day or less having significantly fewer pretreatment criteria. Local sewer utilities may not consider flows in establishing the number of criteria, however.

The PCBF Sector has been subject to intense regulatory scrutiny. All penalties incurred during the planning period were for violations of wastewater pre-treatment limits. No penalties have been levied upon PCBF facilities by the Department of Ecology during the planning period.

CHAPTER 3
Analysis of the PCBF Sector

Extracting Sector Data

In the process of extracting information out of the P2 Plans, APRs, and Annual Dangerous Waste Reports, the Team noted tremendous variability in the way facilities described wastes, substances, processes, and opportunities. Examples of these disparities include:

- Substance descriptions varied. Some facilities used trade names, other identified the specific chemicals contained in the substances. Even the spelling of substance names varied.
- Waste descriptions varied. Some facilities identified specific wastes, while some used Annual Dangerous Waste Report descriptions. There were also significant errors in Annual Dangerous Waste Report data, particularly in designation.
- In some cases it was difficult to determine the purpose of the reduction opportunity. Facilities generally provided an opportunity title and no description of the function of the opportunity.

In order to compile and compare data, reasonably standard names were assigned by the Sector Team to specific processes, wastes and substances. This was necessary to make the data more meaningful, and to establish a basis to compare the activities of each facility. Naturally, standardization compromised some specificity in favor of enabling analysis of the pollution prevention activities for these facilities.

Not all of the facilities associated targeted substances or wastes with a specific manufacturing process or P2 opportunity. The sector team made no attempt to correlate substances and wastes to opportunities or processes that did not identify targeted substances or wastes. Twenty-one processes, twenty hazardous substances, and twenty-nine waste streams were identified after standardization. These are listed in Table 3 and Table 4.

Classes of reduction opportunities were also standardized. The entire standardized list of opportunities with implementation status is listed in Appendix A.

Ecology's Reduction Opportunities Database (ROD) was used to compile and store the voluminous data on the sector's processes, wastes, and P2 opportunities. The ROD was modified in order to manage the variety of data available to the Sector Team.

Table 3: Standardized Processes

PROCESS NAME	DESCRIPTION
Black Oxide/Chlorite	Apply oxide coating to inner layer surfaces prior to lamination - intended to promote adhesion in multi-layer lamination.
Clean	Mechanical or chemical methods to remove surface contamination prior to further processing. Oxide removal occasionally found in this category.
Deburr	Chemical or mechanical means of removing copper burrs following mechanical processing. Compressed disk scrub and acid immersion are most common.
Develop/Etch/Strip	DEVELOP - removal of unpolymerized photoresist following exposure, creating circuit pattern, typically with sodium carbonate monohydrate. ETCH - chemical removal of exposed copper via redox reaction, typically with ammonia-based etchant. Etching follows solder plate and resist strip in additive processes. STRIP -removal of polymerized resist after plating or etching, exposing metal surface.
Drilling	Mechanical drilling of copper-clad laminate or following external plane lamination for multi-layers. Holes are used for inter-layer connections or component mounting. Often use phenolic paper and/or aluminum as entry and exit material.
Electroless/Other	One of several techniques for applying a thin conductive layer of material on non-conductive hole walls. Traditional electroless copper uses formaldehyde, persulfate conditioners, palladium-tin activators, sulfuric acid, etc.
Fab Artwork	Preparation of image to be used in exposure of circuit pattern. Master films are generally produced in a photographic process using silver halide film and digital photoplotters. Wastes are identical to photo labs. Working film is often diazo, using ammonia for developing medium.
Fusing/IR Flow	Temporary melting and freezing of solder on the surface to enhance appearance and solderability of solder on printed circuit surface. Usually infra-red or convection ovens, oil immersion.
Gold & Nickel Plate/Strip	Selective addition and removal of precious metal, often used for connectors or special mounting sites. Cyanide chemistries common.

PROCESS NAME	DESCRIPTION
HASL	(SMOBC Process) Hot air solder level - temporary immersion of circuit board in molten solder. Excess solder removed with low pressure hot air. Used to promote solderability of copper prior to assembly.
Injection Molding	Ancillary process in sector facility. Not a traditional PCBF process.
Maintenance	Facility and equipment maintenance in PCBF facilities.
Painting	Ancillary process for sector facility. Not a traditional PCBF process.
Purchasing	Materials and equipment purchasing in PCBF facilities.
Silk Screening	Screening of plating resist, photoresists, soldermasks, and legend inks for various process steps. Typically uses screen emulsion to define printing pattern. Used in low-resolution applications or application of photo-imageable material.
Smear Remove	Chemical or plasma removal of epoxy residues after drill operation (drill smear). Typical chemistries include permanganate and sulfuric acid.
Solder Mask	(SMOBC Process) Dry film, liquid photoiniageable or screened polymeric material applies to protect circuit pattern from mechanical damage and unwanted solder coating during HASL. Inks and sodium carbonate developer used.
Wastewater Treatment	(WWT) Treatment of rinsewaters and spent solutions, usually after central collection. Metals such as copper and lead of principal concern. Sodium hydroxide precipitation largely supplanted by alternative precipitation technologies.

Table 4: Standardized Substances & Wastes

HAZARDOUS SUBSTANCES	HAZARDOUS WASTES
Anhydrous Ammonia*	Acetone Still Bottoms
Ammonia Compounds*	Alkanessulfuric Acid
Ammoniacal Etchant	Ammonium Bifluoride
Copper Metal*	Copper Hydroxide Sludge
Copper Sulfate*	Cyanide Solutions
Fluoboric Acid	Degreasing Solvents
Formaldehyde*	Dibasic Acid Esters
Glycol Ethers	Fluoboric Acid
Hydrochloric Acid*	Glycol Ethers
Isopropyl Alcohol*	Hydrogen Peroxide
Lead*	Isopropyl Alcohol
Methanol*	Laminate Contaminated with Monethanolamine
Nickel Compounds*	Lead Coated Trim
Nitric Acid*	Nickel Chloride
Phosphoric Acid*	Nickel Fluoborate,
Potassium Peroxymonosulfates	Nickel Sulfamate
Sodium Chlorite	Nitric Acid
Sodium Hydroxide	Paint Still Bottoms
Sodium Permanganate	Peroxide
Sulfuric Acid	Petroleum Distillates
	Phosphoric Acid
	Potassium Cyanide
	Rosin Solder Flux
	Silver Flux Fixer
	Sodium Permanganate
	Spent Ammoniacal Etchant
	Spent Carbon
	Thiourea

The “*” in the above list notes those substances that are listed as a TRI chemical.

Analysis of Sector Data

The analysis of sector data was done in three stages:

1. Qualitative Analysis-To determine the sector's relative commitment, progress and motivations.

2. Sector Profile Analysis-To determine the industry standard, and technical assistance needs.

3. Quantitative Analysis-To determine if pollution prevention efforts are successful.

Each of these stages are discussed in the following sections. Each section contains a brief overview of its objectives, data limitations, analysis, and summary. Both the Qualitative Analysis and the Sector Profile Analysis are based, in part, on queries of Ecology's Reduction Opportunities Database.

Qualitative Data Analysis

This section evaluates P2 opportunities and their implementation status during the planning period. This evaluation is done in the following manner:

1. Explore the limitations of the qualitative data.

2. Examine P2 opportunity distribution by implementation status. This examination provides insight into the PCBF Sector's potential for future implementation and need for technical assistance, and the commitment of the industry sector to adopting pollution prevention techniques. In addition, it will attempt to identify and explain the trend found in the implementation status of the opportunities listed by the PCBF Sector.

3. Examine P2 opportunity distribution by facility. This examination provides a yardstick by which individual sector facilities can compare themselves to their peers regarding the number of opportunities identified. The examination also helps Ecology identify the level of technical assistance a particular sector facility may need.

4. Examine P2 opportunities most commonly identified. This examination is done in an effort to provide individual facilities with proven opportunities that potentially required little investment and provided cost savings.

Limitations of Qualitative Data

Facilities are encouraged to list all P2 opportunities implemented prior to beginning the P2 planning process. Opportunities identified during the planning process must be either accepted for implementation, rejected as technically or economically unfeasible, or studied until an appropriate decision can be made. Opportunities accepted and subsequently implemented are identified in Annual Progress Reports (APRs).

The status of each P2 opportunity was tracked from the P2 Plan to the last APR submitted. There were five status categories, defined as follows:

1. Prior to Planning: Reduction opportunities implemented prior to the planning process.

2. Implemented: Reduction opportunities implemented between the time the plan was written and the submittal of the last APR.

3. Selected: Reduction opportunities selected, but not yet implemented.

4. Rejected: Reduction opportunities that will not be implemented.

5. Further Study: Reduction opportunities under technical or economic research.

P2 Plans and APRs rarely document all of the activities qualified as pollution prevention opportunities. For example, facility quality programs and improved maintenance efforts were rarely noted. Pollution prevention efforts are generally under-reported.

Facilities were not interviewed. This decision was made by the Team in conjunction with the Project Coordinator. The Team did not want to overburden the facilities-they were to submit P2 Plans and APRs in September and they were being surveyed by Ecology for another project. The Team thought it would damage Ecology's relationship with these facilities by requesting additional information in a short time frame.

A total of 408 pollution prevention opportunities were identified by PCBF Sector facilities.

Opportunity distribution by implementation status is examined to determine the Sector's implementation potential, commitment/focus and relative need for technical assistance. Figure 1 summarizes P2 opportunity distribution by implementation status.

Figure 1: P2 Opportunity Distribution by Implementation Status

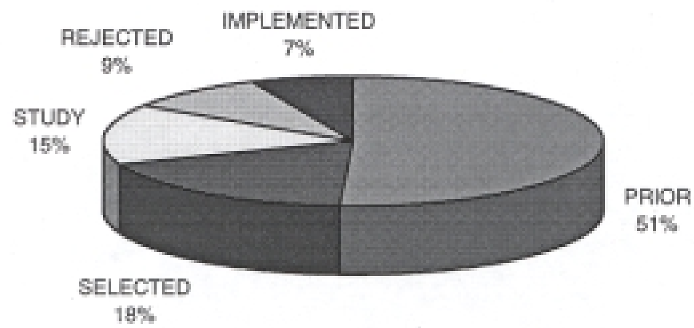


Figure 1 suggests:

- Significant reduction efforts were made prior to the emergence of P2 planning when PCBF Sector facilities implemented one-half of all the P2 opportunities they identified. The remaining fifty percent of the P2 opportunities were identified during the preparation of Pollution Prevention Plans.
- The PCBF Sector still has a number of opportunities to implement. Most of the P2 opportunities identified (75%) have either been implemented prior to planning, implemented during planning, or have been selected to be implemented.
- An exceptionally low number of the opportunities identified in P2 Plans (9%) were rejected outright.
- There are areas in which PCBF facilities are still seeking answers and may need additional technical assistance. Twenty-four percent of the total number of P2 opportunities identified have been rejected or are undergoing further study.

When P2 opportunity status is prioritized based on the number of P2 opportunities identified, they rank as follows:

1.	Opportunities implemented prior to planning	206
2.	Opportunities selected for implementation	75
3.	Opportunities under further study	62
4.	Opportunities rejected	37
5.	Opportunities implemented since planning was conducted	28

PCBF Sector facilities were not interviewed. Only speculations can be made as to why the above breakout of P2 opportunities exists. In an attempt to explain this ranking, the factors having a great influence on sector facilities-market trends, regulatory environment, and technical assistance-will be discussed.

A great de al of P2 implementation has been done prior to these facilities' P2 Plans being written. Reasons for this could be increased market competition and regulatory cost. As market competition increases, so does the need to reduce operating costs. Many of the opportunities implemented prior to planning can be characterized as "low hanging fruit" - i.e., reduction opportunities with little or no capital investment, a very high return on investment, or both. These opportunities can often be characterized as cost saving measures with tangible environmental benefits. Regulatory limits could strongly influence specific opportunities (e.g., Montreal Protocol, wastewater discharge limits). No attempt was made in the P2 Plans to characterize the quantity of waste reduced or the economic benefits achieved by these efforts.

In addition, the PCBF Sector's emphasis on P2 opportunities implemented prior to planning may result from the facilities' attempts to demonstrate or establish their environmental credibility. These facilities had been given a great deal of regulatory attention prior to the inception of the pollution prevention planning process.

The rank order for PCBF Sector P2 opportunities not implemented prior to planning could result from:

- Ecology's past technical assistance efforts emphasized plan development relative to implementation.

- Optional plan implementation. Facilities are required to write P2 Plans, but implementation is optional.

- The planning process caused facilities to take a more encompassing look at their processes. Thus implementation, and its timing, must be coordinated with budget cycles and other internal activities.

P2 opportunity distribution by facility is examined to provide a measure by which individual sector facilities can compare themselves with their peers regarding the number of P2 opportunities identified. It also helps Ecology identify the level of technical assistance a particular sector facility may need.

Table 5 lists the number and implementation status of opportunities by facility name.

Table 5: P2 Opportunity Status[1]

Facility	Prior to Planning	Implemented	Selected	Rejected	Further Study	Total Opp. Identified
Circuit Partners Inc.	25	4	11	4	4	**48**
Circuit Services Inc.	9	0	20	1	12	**42**
Circuit Technology Inc.	85	0	6	6	2	**99**
Circuits Engineering	3	0	0	0	0	**3**
Eldec Corporation	11	4	6	6	4	**31**
Fluke Corp.	22	3	0	6	12	**43**
Key Tronic Corp.	7	0	2	5	7	**21**
Pacific Circuits Inc.	12	0	16	0	5	**33**
Precision Circuits Inc.	7	4	1	0	5	**17**
Samnina Corp.	20	7	8	9	5	**49**
Universal Mfg. Corp.	5	6	5	0	6	**22**
TOTAL	**206**	**28**	**75**	**37**	**62**	**408**

PCBF Sector facilities identified an average of thirty-eight opportunities. Note that (with one exception) a large number of opportunities were identified at each facility. There is a weak correlation between the number of P2 opportunities identified and the size of the facility. However, size does not appear to be a decisive factor in determining the number or status of identified opportunities.

Conclusions cannot be drawn regarding a facility's pollution prevention efforts solely on the basis of the number of opportunities identified. Since all sector facilities received technical

[1] This table and this report do not include 16 opportunities that were defined so incompletely that the status for those opportunities was not discernible.

assistance from Ecology in a variety of forms and at varying levels, Ecology cannot draw conclusions regarding the efficacy of sector facilities' efforts on the basis of this data. Future technical assistance efforts may consider the extent to which individual facilities undertook these tasks.

Below is a list of "PCBF Industry Top Ten P2 Opportunities" ranking the most frequently accepted or studied P2 opportunities. These opportunities frequently reduce both hazardous waste generation and hazardous substance use. The ranking within the top ten is arbitrary when opportunities have equivalent frequency.

PCBF Industry Top Ten P2 Opportunities by Frequency

1. Electrolytic recovery of metal from rinses and process baths
2. Drag-out reduction techniques (hang times, misting, drain boards, etc.)
3. Statistical and/or process controls to extend bath life
4. Use coated racks to reduce nitric acid rack strip
5. Use spent baths for wastewater treatment pH adjustments
6. Install counter-current rinsing
7. Substitute tin etch resist for tin-lead
8. Regenerate spent etchant (elochem, cupric chloride, etc.)
9. Automate rinsewater addition*
10. Ion exchange and electrolytic recovery on rinses, spent baths*
11. Recycle tin-lead stripper*

Those opportunities marked with an "*" are all ranked 10. Many of these opportunities were common to several of the facilities. Interestingly, no single opportunity was universally accepted by all facilities.

The distribution of opportunity status indicates that much of the "low-hanging fruit" has been harvested. These opportunities require little capital investment and were cost saving measures broadly implemented prior to the planning process.

Appendix A lists standardized P2 opportunity names and the implementation status of each of those opportunities for the entire sector. Appendix A serves as a "shopping list" of P2 opportunities provided by the sector. Such a list has the potential to enable each facility to benchmark their opportunity list against the sector as a whole. This list might also prove invaluable for the preparation of future P2 Plan updates, and as a tool for future technical assistance efforts.

Summary of Qualitative Analysis

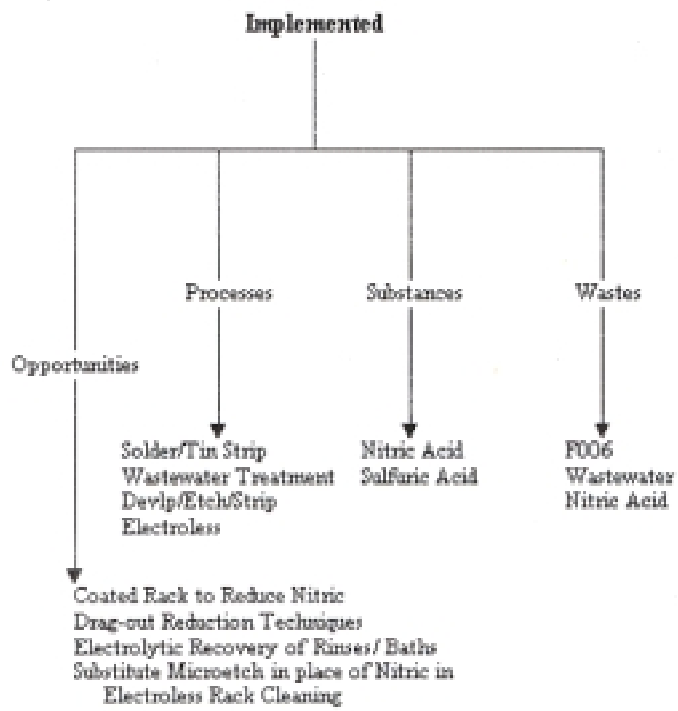
Based on this qualitative analysis, Ecology has determined:

Significant reduction efforts were made by the PCBF Sector facilities outside of the context of pollution prevention planning.

- The PCBF Sector still has a number of P2 opportunities to implement.
- The PCBF Sector rejected a low number of the opportunities identified in their P2 Plans.
- There are areas in which PCBF facilities are still seeking answers and may need additional technical assistance.
- There is a broad acceptance of pollution prevention techniques across most sector facilities. The number of opportunities are broadly distributed, with an average of thirty-eight opportunities identified per facility. All but one facility identified opportunities on the same order of magnitude as the sector mean.
- The rate of acceptance of opportunities seems to correlate to the amount of capital investment required - with greater capital investment requiring notably longer implementation periods. Waste reduction efforts emphasized rinsing and wastewater treatment, process controls and management of spent process baths. Substance use reduction emphasized drag-out reduction techniques, process controls, alternatives to electroless plating, and reclamation of spent baths.

Sector Profile Analysis

A Sector Profile was developed to identify by opportunity status-Prior to Planning, Implemented, Selected, Rejected, and Further Study-the priority opportunities, processes, substances and wastes for PCBF facilities. The Sector Profile is displayed in entirety as Figure 2 on page 29. Below is a segment of the Profile illustrating P2 opportunities implemented since P2 planning was conducted by PCBF facilities and the processes, substances, and wastes associated with those opportunities.



The Sector Profile will:

1. Determine the sector standard. -Elements in the Sector Profile identified under the status "Prior to Planning," "Selected," and "Implemented" establish opportunities, processes, substances and wastes on which the PCBF Sector has previously or is currently concentrating its P2 implementation efforts. In theory, these elements should require little capital investment, provide cost savings, and outline a P2 standard for the Sector.

   The sector standard will allow PCBF facilities to compare and focus their P2 efforts. It will also help to direct Ecology's technical assistance efforts at existing PCBF facilities and any new ones.

2. Determine the Sector's P2 focus for the future and technical assistance needs. Elements in the sector profile identified under the status "Rejected" and "Further Study" tell us which opportunities, processes, substances and wastes Sector facilities are going after, but have not had much success with. This will help Ecology to direct its future technical assistance efforts.

   For example: Spent etchant is identified as a targeted waste stream under the opportunity status of "Rejected" and "Further Study." This sends the message to Ecology that technical assistance is needed to address spent etchant as a waste stream.

3. Determine if reductions of targeted substances and waste streams have occurred. The Sector Profile identifies substances and wastes that have been reduced as a result of opportunities implemented prior to and during planning. Reductions in these substances and wastes are potentially measurable through planning documents and Annual Dangerous Waste Reports. Issues pertaining to the measurement of substance and waste reduction will be discussed in Quantitative Analysis-Trends in Waste Generation.

The Sector Profile is subjected to the same data constraints as those described under the Qualitative Analysis. Below, the methodology used to develop the Sector Profile is discussed.

Five queries of Ecology's Reduction Opportunities Database were used to develop the Sector Profile. The queries included an alphabetical list of P2 opportunities with corresponding process, substances, wastes, and number of facilities identifying that opportunity for each of the opportunity status categories. The number of facilities acts as a weighting factor to prioritize the data elements (opportunities, processes, substances and wastes). Using the number of facilities rather than the number of times a particular element is identified, irrespective of the facility, minimized the outside influences.

The profile could be unduly influenced by a number of things including facility size as defined by level of production, waste generation, processes used, and level of staff expertise. For example: If a facility generates far more waste nitric acid than the other facilities, the anticipated impact would be that this facility would focus on this waste stream. Thus, the facility would develop staff expertise in this waste stream and potentially generate far more opportunities relating to nitric acid than would other Sector facilities. So, this facility's focus on nitric acid could skew the data to make it appear that nitric acid was a top priority for the Sector rather then just this facility. That is, if the total number of opportunities related to a waste was the only factor used to develop the Sector Profile.

Summary of Sector Profile Analysis

The Sector Profile (Figure 2) examines the pollution prevention opportunities most commonly identified by PCBF facilities and the processes, substances, and wastes associated with those opportunities. This provides a profile of the PCBF Sector's past, present, and future areas of focus in pollution prevention. Please consult Figure 2 on page 29 for specifics.

The Sector's priorities for opportunities implemented "Prior to Planning," "Implemented" during planning, and "Selected" for implementation are:

Opportunities: Reduce water use, extend bath life, reduce nitric acid strip, and electrolytic recovery.

Processes: Wastewater treatment, develop/etch/strip, electroless and electroplating.

Substances: Nitric acid and sulfuric acids, followed by sodium hydroxide and lead.

Wastes: Wastewater, wastewater sludge (F006), sulfuric acid, and nitric acid.

PCBF facilities can use this list to compare and focus their pollution prevention efforts to ensure they are as competitive as their peers on the pollution prevention front. This list directs Ecology's technical assistance efforts when working with PCBF facilities to implement P2 and help ensure a level playing field by defining a P2 standard for the sector.

In addition, identification of these targeted substances and waste streams should make it easier for Ecology to determine if reductions have occurred as a result of pollution prevention efforts.

The sector's priorities for opportunities "Rejected" and those under "Further Study" are:

Opportunities: Install sludge dryer, on-site regeneration of spent etchant, evaluate alternative technology to electroless plating.

Processes: Wastewater treatment, develop/etch/strip, and electroplating.

Substances: Etchant, and sulfuric acid.

Wastes: Wastewater, wastewater sludge (17006), and spent etchant.

These are areas where Sector facilities have not had much success, and where Ecology needs to direct its future technical assistance efforts. Some areas such as wastewater treatment have been improved through P2 implementation as noted above, but the need for further improvements persists and as a result, a priority may appear in both categories ("Implemented" and "Further Study").

Figure 2: Sector Profile

Figure 2

Sector Profile for the Printed Circuit Board Fabrication Sector in Washington State

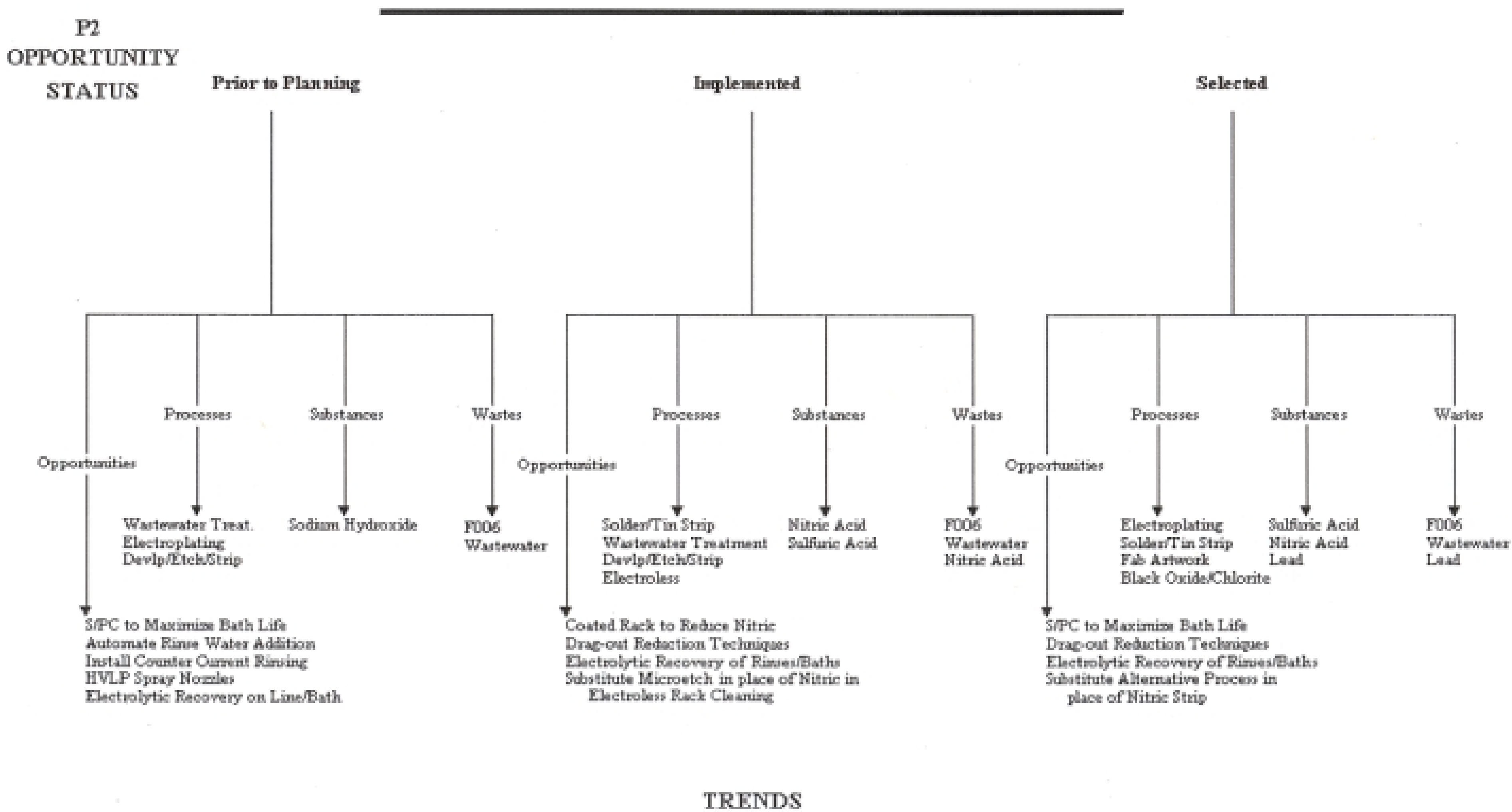
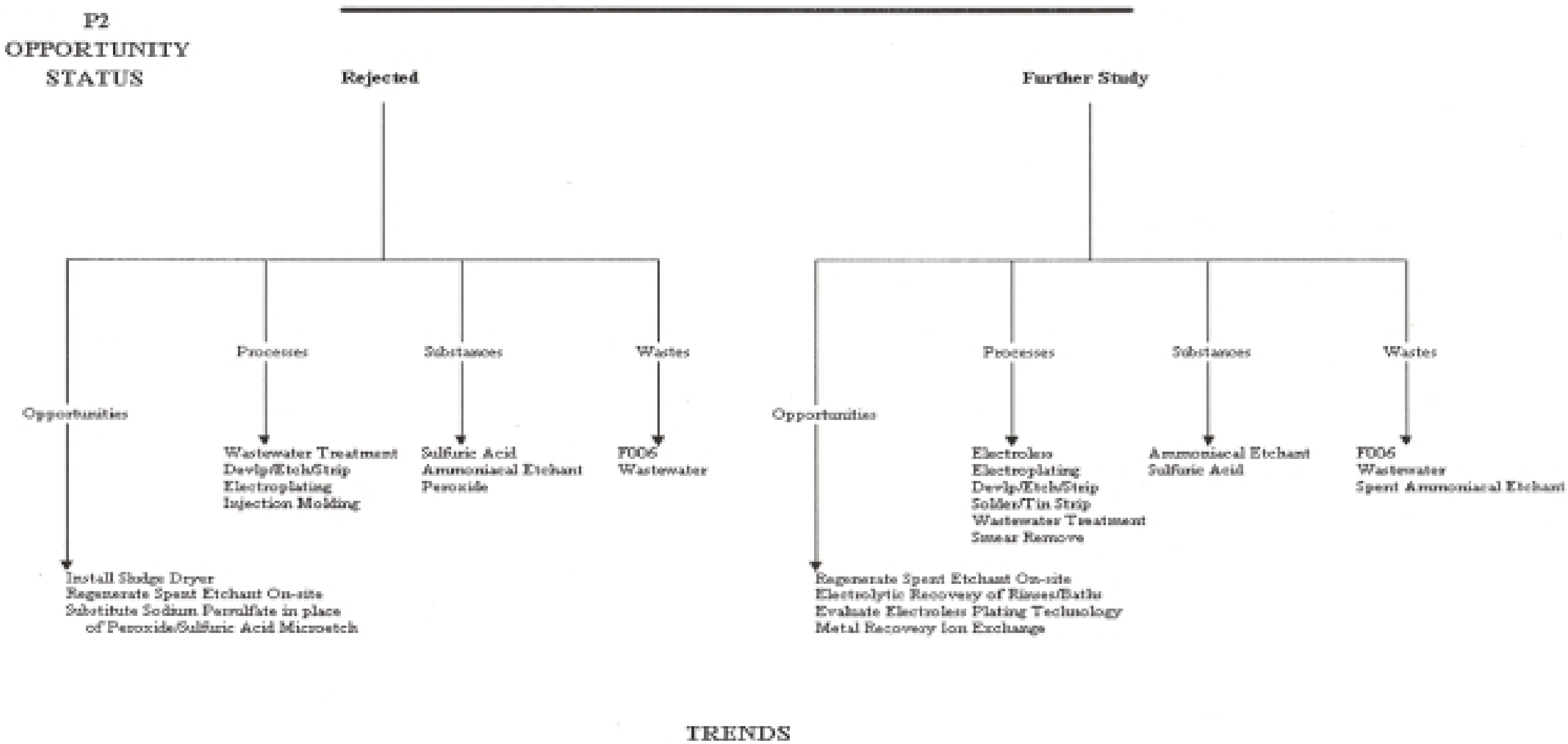


Figure 2 CONT'D

Sector Profile for the Printed Circuit Board Fabrication Sector in Washington State



Quantitative Analysis - Trends in Waste Generation

This section evaluates quantitative waste generation data for the sector during the planning period. Waste identified in the Sector Profile will be included in this analysis. Techniques to normalize waste generation data for increasing production are applied.

No attempt will be made to determine the sector's hazardous substance use reductions as data integrity was a significant concern in P2 Plan review. Generation data from Annual Dangerous Waste Reports was used to determine actual waste reduction - in lieu of P2 Plan reduction data.

Hazardous Waste Data

1. **Conflicting Data Sources.** Annual Dangerous Waste Report data is used. The integrity of the data from P2 Plans presents a significant concern when the plan reduction data is compared to the quantities reported in the Annual Dangerous Waste Reports. Plan data claim nominal reductions in overall waste generation, Annual Dangerous Waste Report data suggest significant increases in waste generation. Annual Dangerous Waste Report data is verified by the manifest system, while P2 Plan data remained largely unverified.

2. **Counting Wastewater.** Facilities reporting wastewater report it as a dangerous waste under pen-nit-by-rule. Wastewater is by far the largest waste stream from the industry sector. It is likely that dangerous waste totals are under-estimated by the sector's dangerous waste reports. Influents to the wastewater treatment processes that designate as dangerous waste must be counted in Annual Dangerous Waste Reports. These waste streams often designate for heavy metals, such as lead - or have the potential to designate for fish toxicity, due to high copper content.

3. **Misdesignation of Waste Streams.** A review of the Annual Dangerous Waste Report data also found disparity in designation. For example, wastewater treatment sludge from PCBF processes is typically a listed waste. Sector facilities reported this waste in a number of ways, often not carrying the federal listing.

Hazardous Substance Data

Hazardous substances to be considered in pollution prevention planning are determined by the Superfund Amendments Reauthorization Act (SARA) Title III Section 313 list. These chemicals comprise the Toxic Release Inventory (TRI) list and require annual reporting from facilities handling quantities above threshold amounts.

Hazardous substance use presents some unique problems for the sector analysis.

1. **Changes to the SARA Title III Section 313 List.** During the planning period, over 200 substances were added to the TRI list. Simultaneously, two chemicals were removed from the list - sulfuric acid and sodium hydroxide. These two chemicals are probably the most common in the PCBF process. The deletion of these chemicals negatively impacted data integrity since some facilities continued to report on these substances, while others did not. The scope of the project did not allow detailed facility assessments, therefore the data was deemed unreliable without verification. Copper metal may be the most prevalent SARA Title III chemical in the PCBF process and its inclusion in pollution prevention planning data for this sector may not be meaningful.

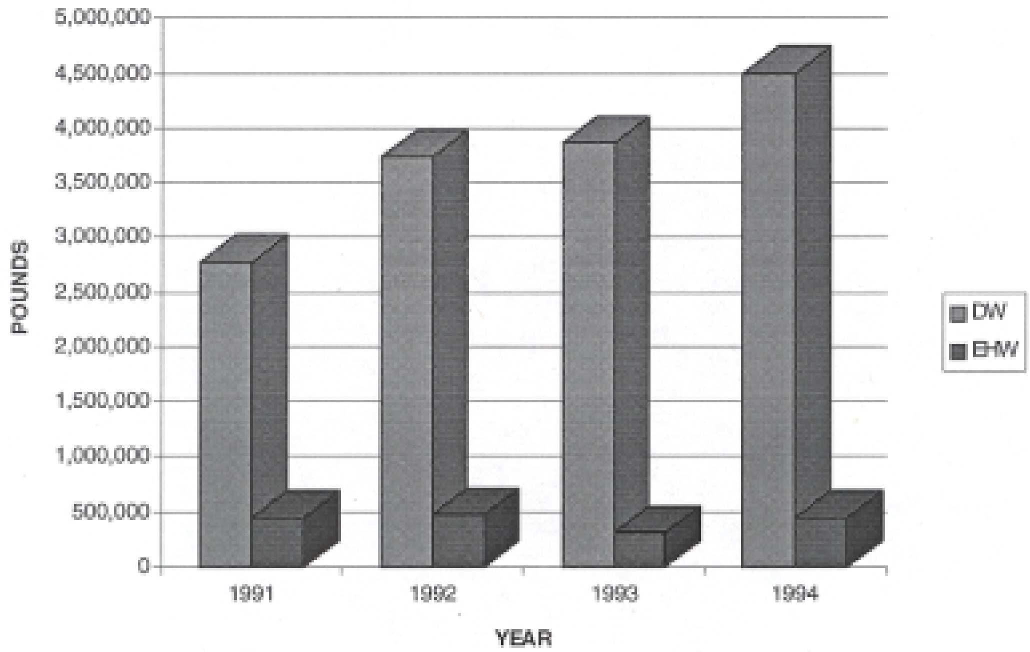
2. **Lack of Material Purchase or Consumption Data in P2 Plans.** Reporting of total TRI chemicals used is not a required element of P2 Plans, so no mechanism of verification of reported reductions exists. The hazardous substance use data is not considered reliable, and will not be presented in this report.

Analysis of Waste Generation

The quantity of waste generated by sector facilities was compiled from the Annual Dangerous Waste Reports. The raw generation data is presented segregated into dangerous waste (DW) and extremely hazardous waste (EHW) categories. Specific indicator waste streams (based on the Sector Profile) are identified and used to analyze trends in waste generation. Wastewater is treated independently to prevent the wastewater totals from diluting the results of other waste reduction efforts. Finally, data is normalized using weighted production factors. The weighting of production factors is to account for the greater influence of large waste generators on trend data.

Figure 3 presents the annual waste generation report data for the sector during the 1991-1994 planning period. The waste is separated into dangerous waste and extremely hazardous waste, and does not include wastewater.

Figure 3: Trends In Waste Generation For PCBF Facilities



While waste totals increase significantly over the planning period, the quantity of extremely hazardous waste generally decreased. This could be interpreted as a decrease in overall waste stream toxicity. The trend is also noteworthy because recent improvements in wastewater treatment methods have greatly increased the metals content in wastewater treatment sludges, increasing the possibility of designation as an EHW. State rule changes have recently, eliminated the EHW designation, for state toxicity.

Table 6 summarizes total waste generation for the 1991-1994. Extremely hazardous waste, dangerous waste and wastewater streams are compiled individually.

Table 6: Annual Dangerous Waste Report Data (lbs)

	1991	1992	1993	1994
Total EHW	253,993	485,105	311,345	448,055
Total DW	2,776,109	3,730,997	3,884,103	4,406,788
Total EHW + DW	3,030,102	4,216,102	4,195,448	4,854,843
Total Wastewater	256,418,607	398,397,000	214,072,000	219,177,000

The increase in waste generation conflicts with expectations based on the large number of reduction opportunities implemented. This may be due, in part, to the increasing complexity and density of printed circuit boards, and/or quality criteria of printed circuit board consumers. At the same time, the sector is enjoying a growth period, where cost containment and process efficiency are not deemed as important as satisfying delivery and quality criteria.

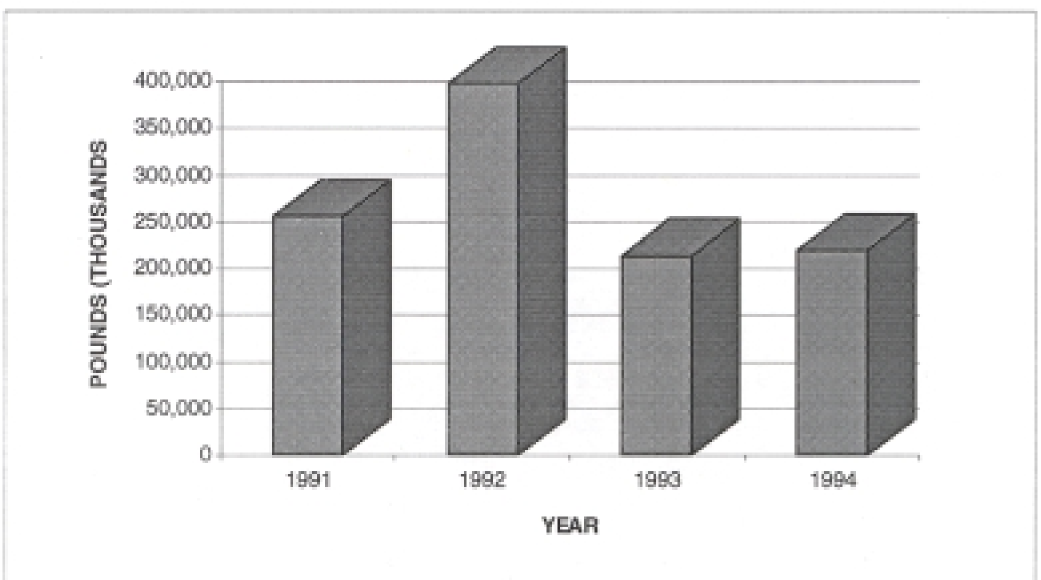
Analysis of Wastewater

Wastewater is treated in both batch and flow-through systems. The majority of wastewater is derived from rinsing circuit boards. The spent bath chemistries are typically batch treated.

PCBF Sector facilities report wastewater as DW (waste codes D002, D008, and WT02). Data on wastewater from the sector is dominated by a few facilities and cannot be relied upon for trend analysis. No data on total flow to or from facilities was available. One of the largest generators of wastewater also discontinued production during the planning period, perhaps lending a misleading impression about wastewater trends.

Figure 4 displays total wastewater quantities reported on Annual Dangerous Waste Reports by sector facilities. The increase in wastewater reported in 1992 and the decrease reported in 1993 were due largely to one facility beginning production and another facility ceasing production in those years. While the overall trend of the graph appears encouraging, the designation of wastewater as a DW increased over the planning period for the remaining ten facilities. Again, this conflicts with the expectations from the qualitative analysis where one might expect a reduction in wastewater generation as a result of broad based implementation of P2 techniques.

Figure 4: PCBF Wastewater Designating as Dangerous Waste



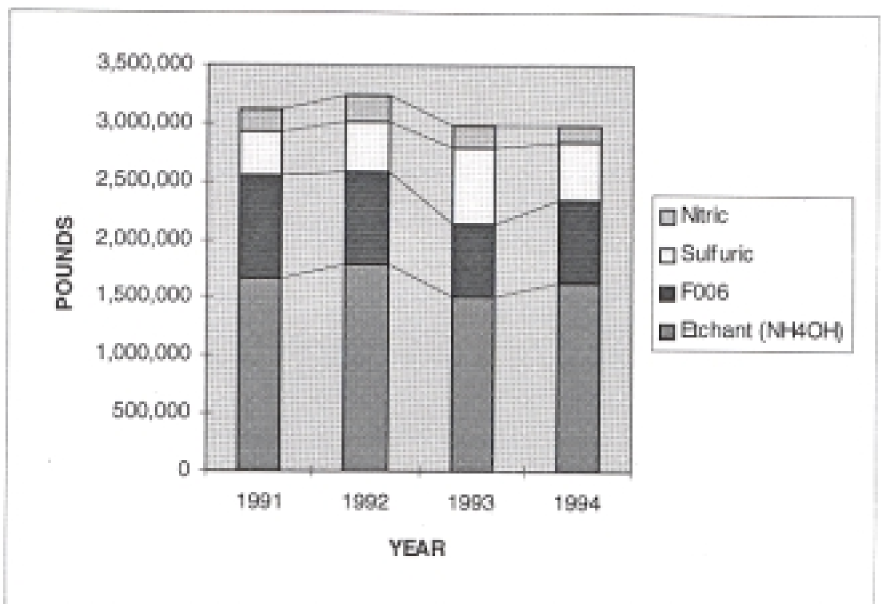
Time permitting, future sector analyses would benefit from water use and discharge data, as well as acquiring detailed profiles of sector effluents and discharge monitoring reports (DMRs). Again, given the regulatory activity of local sewer districts, wastewater may be an opportunity for sector-wide emphasis.

Analysis of Target Waste Streams

The Sector Profile identified several wastes affected by common pollution prevention opportunities selected for implementation. In particular, wastewater treatment sludge, nitric acid from rack stripping, spent etchant and sulfuric acid were reduction targets for several opportunities.

Figure 5 displays the waste generation trends for these targeted waste streams.

Figure 5: PCBF Sector Generation for Target Waste Streams



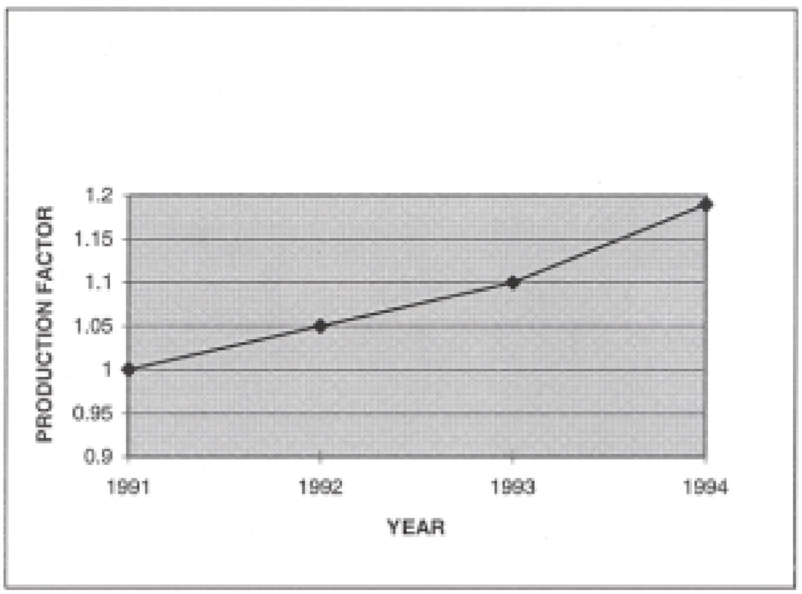
For these waste streams (with the exception of sulfuric acid), reductions can be seen across the sector. While these reductions cannot often be traced to specific opportunities, there is evidence that pollution prevention techniques are affecting the volumes of these specific waste streams. These trends are more evident if the data are normalized for the significant increase in production across the sector during the planning period.

Analysis of Data Normalized for Production

While the quantity of waste generated by PCBF sector facilities has increased substantially during the planning period, so has the rate of production. To account for the increase in production, the data was normalized using a "weighted production factor." The weighted production factor was determined by taking the products of individual production factors and the percentage of total waste generated by the facility. In this way, companies who generate more waste (hopefully by virtue of greater production) also have greater influence on the value of the production factor for the sector.

Figure 6 shows the annual production factors for the sector. These data show a steady increase in the rate of production for the sector. In fact, 1994 production was one hundred and twenty-six percent of 1991 - demonstrating high single-digit growth for the planning period. One facility has shown an eighty percent increase in production over the planning period. This trend reflects a strong electronics and manufacturing environment in Washington State.

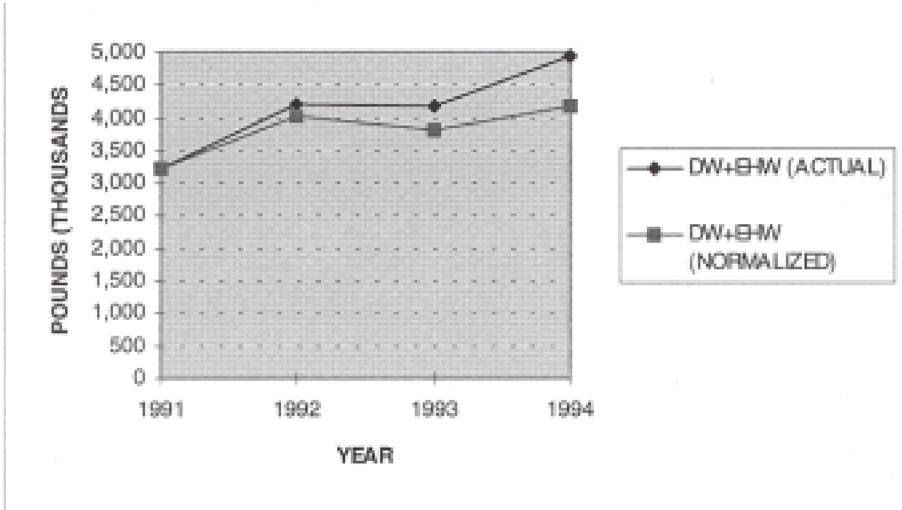
Figure 6: PCBF Weighted Production Factor



NOTE: 1991 was used as the base year for the PCBF Sector Production factor (1991 1. 0). Increases or decreases in production were measured from that starting point.

However, waste quantities have increased faster than production. By dividing annual waste quantities by the weighted production factors, we can compare the rate of waste generation per unit of production. Figure 7 shows the rate of waste generation (wastewater not included) in terms of 1991 production. Unfortunately, the rate of relative generation increases approximately twenty percent over the planning period, even after normalization for production. This is surprising in light of the number of pollution prevention opportunities selected or implemented.

Figure 7: Waste Generation Normalized to 1991 Production



Given this result and the large number of opportunities implemented, the extent to which opportunities are implemented becomes subject to scrutiny. In the absence of significant changes in production techniques or product mix, the data suggests that the benefits of implementing pollution prevention techniques have not been fully realized. For example, using drag-out reduction techniques and counter current rinsing are effective only if a commensurate reduction in rinsewater use is enacted. If quality criteria are not established for respective rinsewater contamination levels, then it becomes impossible to establish appropriate rinsewater flows. Further, process controls such as conductivity actuated solenoid valves, panel counters or timers must be installed simultaneously to insure that flows remain appropriate for changing process conditions.

Summary of Quantitative Analysis

It appears some progress has made to reduce the generation of extremely hazardous wastes since 1992. There is a significant increase in dangerous waste generation across most facilities. Production within the PCBF Sector has increased twenty-six percent over the five year reporting cycle. Normalizing waste generation by weighting the production factors yields more insight into the actual trends for the industry sector. However, the normalized data still shows an increase in waste generation.

Reductions are seen in waste streams identified through the Sector Profile. While these reductions cannot often be traced to specific opportunities, there is evidence that pollution prevention techniques are affecting the volumes of these specific waste streams. These trends are more evident if the data is normalized for the significant increase in production across the sector during the planning period.

Substantial increases in demand, changing technologies and improved environmental reporting all contribute to increases in waste generation reported. The extent to which opportunities are implemented, as reported in the P2 Plans, Executive Summaries, and Annual Progress Reports varies widely. Taken as a whole, the list of opportunities is most useful in establishing a repertoire of opportunities available to the industry. Judging from waste generation trends, it is likely that significant opportunities for further reductions remain.

CHAPTER 4
Conclusions

Conclusions Drawn From Sector Data Analysis

In 1995, HWTR began to evaluate the implementation status of pollution prevention efforts in the Printed Circuit Board Fabrication Sector. The sector approach does the following:

1. Provides feedback to facilities on pollution prevention progress.
2. Measures the benefits of pollution prevention implementation.
3. Develops a technical assistance strategy to assist industries with their pollution prevention effort.

Pollution Prevention Progress

Significant reduction efforts were made by the sector facilities prior to being required to develop a P2 Plan. Most of these early efforts focused on wastewater and wastewater sludge. The Sector Team feels this is in response to the regulatory attention placed on the sector.

Sector facilities have broadly accepted pollution prevention techniques. Thirty-eight pollution prevention opportunities have been identified on average per facility. Only nine percent of the 408 P2 opportunities identified were rejected and over fifty percent were implemented prior to planning. The implementation status of the P2 opportunities seems to correlate to the focus of regulatory agencies and the amount of capital investment required - with -greater capital investment requiring notably longer implementation periods. In addition, waste reduction may have been given a lower priority in the PCBF Sector due to changes occurring within the market (i.e., increased demand and competition, changing product technology, and rigorous customer specifications). This may explain why only seven percent of the 408 opportunities identified have been implemented since 1991.

Measured Benefits of Pollution Prevention Implementation

Waste generation per unit of production output has increased in the PCBF Sector. Though total waste generation has increased, there has been a decrease in waste toxicity. Taking this one step further, quantities of wastes targeted by implemented P2 opportunities show decreases. This infers that these wastes have been reduced as a result of implemented P2 opportunities.

Wastewater is a majority of the waste generated by PCBF facilities. Typically, wastewater is treated on-site and discharged to industrial sewers under permit-by-rule. Wastewater is the only waste stream to demonstrate significant reductions for the sector. Unfortunately, the reductions are skewed since the majority was achieved by a single facility which ultimately ceased operation. Compliance with wastewater discharge limits, appropriate designation of wastewater streams, and opportunities for reclamation and recycling rinsewaters remain as opportunities for improvement in the PCBF Sector.

Implementation of pollution prevention techniques appears to strongly correlate to capital expense and potential returns. Those opportunities which show promise for further waste reduction in the PCBF Sector should be analyzed for economic benefits, as well as the potential for implementation in other manufacturing facilities. Particular emphasis should be placed on:

- Alternatives to etchant disposal including regeneration and re-use
- Water conservation
- Alternatives to traditional wastewater treatment, and
- An analysis of the value of metal in the waste stream

A lack of reliable data for both hazardous substance use and the economic benefits of P2 implementation make an analysis of the benefits in these areas impossible.

Technical Assistance Strategy

Sector facilities continue to seek answers to technical issues, and need additional technical assistance. These areas include reducing the generation of wastewater, wastewater sludge, and spent etchant; and reducing the use of etchant and sulfuric acid.

Sector facilities are encouraged to:

- Develop a workgroup to focus on both technical and regulatory issues facing them. Potentially, Ecology could be used to facilitate workgroup sessions. This suggestion is made due to the strong market and regulatory forces that impact the PCBF Sector.
- Utilize Ecology's technical assistance program

In addition, Ecology's Permit Assistance Center with assistance from the Department of Community, Trade, and Economic Development has recently begun work on an electronics sector project. The objective of the project is to provide up front information to printed circuit board manufacturers planning to locate or expand operations in Washington State. The purpose of the information will be to:

- Expedite facility siting
- Encourage early pollution prevention planning
- Foster better understanding between industry and government of their respective roles and responsibilities

Project staff will develop and distribute two packets of information. One packet will be for assemblers and manufacturers. This packet will contain information on Washington State environmental permit requirements, considerations in choosing a site, and suggestions on how to reduce environmental impacts.

The other packet will be for state and local government. This packet will contain information on general manufacturing processes and business culture, business needs in relation to environmental permitting and approvals, and a list of the permits and approvals usually required.

The information packets will be available beginning in February 1997. If you have suggestions or questions contact Mary Ellen McKain at (360) 407-6927.

Ecology's Method for Outreach

Ecology outreach efforts should emphasize:

1. Proven successes, through publication of findings.
2. Formation of a local industry work group.
3. Workshops.
4. Implementation projects or other on-site efforts.

On-site efforts should emphasize multi-disciplinary cooperative efforts, cross-regional where appropriate.

Emerging Opportunities in Pollution Prevention

Several notable P2 opportunities have recently emerged which may affect waste generation trends in the PCBF Sector. Efforts to improve process efficiency, streamline regulations and maximize recycling have long-term effects in sector waste management practices. Technological advances and environmental regulation are evolving simultaneously, and both should seek to serve the mutual interests of the environment and the business community.

Pollution Prevention Opportunities: On-site Technological Advances

It is impossible to characterize all new opportunities in processes as complex as those used in PCBF, but several innovative techniques have been successfully employed in Washington State. A brief discussion of some of the successful methods that are being used at PCBF facilities are outlined below.

Advanced Electrolytic Recovery

Electrolytic recovery of metals from spent process baths and concentrated rinses has been used in the printed circuit industry for a long time. Traditional electrolytic systems have been relatively inefficient, only capable of treating metal bearing streams to a level of approximately 100 mg/l. Recent improvements in electrolytic technology have greatly improved the treatment efficiencies - in some cases as much as two orders of magnitude.

The key to the advanced systems is improvement of electrode design. Woven, flow-through electrodes have much higher relative surface area, facilitating better metals recovery. Electrode materials, such as iridium are also reported to enhance performance. One PCBF facility in

Washington State is using electrolytic recovery as its sole means of wastewater treatment, successfully meeting copper and lead limits of 1.0 and 0.4 mg/l, respectively, in batch treatment applications.

Obvious savings in such a system include eliminating most waste treatment chemicals (pH adjustment is required, however), virtual elimination of sludge, and recovery of semi-precious metals for sale. Current regulatory interpretation treats the recovered copper as a co-product rather than a waste. This technology could also readily be adapted to applications other than waste treatment.

Alternatives to Hydroxide Precipitation

Virtually all PCBF facilities have investigated some alternative to hydroxide precipitation for waste treatment. Alternatives to sodium hydroxide, including lime and magnesium hydroxide, have been the subject of scrutiny for some time. Alternative chemistries such as sodium borohydride, MRT^{R}, and proprietary mercaptan systems have been shown to greatly reduce sludge volume and water content. The selection of specific technologies appears to depend primarily on economic benefits and the sewer discharge limits for metallic ions such as iron.

Alternatives to Electroless Plating

Most PCBF facilities have also investigated some alternative to traditional electroless plating. In addition to carrying a relatively high cost, electroless plating uses formaldehyde as a reducing agent, chelating agents like EDTA, and frequently contains additives like cyanides and sulfides. Proprietary chemistries such as direct metalization, Shipley's "Crimson" and MacDermid's "Black Hole" technologies are having varying degrees of success in the industry. No dominant technology has yet emerged.

Fully Automated Rinsewater Addition

At differing levels, PCBF facilities have employed process control techniques on rinsewater addition. Advanced methods such as centralized conductivity and temperature control are being successfully used in Washington State. Personal computer based systems, using proportional integral derivative (PID) controllers, temperature and conductivity sensors, and solenoid valves are being used to maximize rinse efficiency. Automated rinsewater addition has the flexibility to adjust to changing process conditions while minimizing water use and still meeting rinse quality criteria. The reduced use of rinsewater saves water treatment chemicals, reduces sludge volume, and generally increases wastewater treatment efficiency. The use of de-ionized water in all process rinses also improves rinsing and reduces sludge volume.

Hybrid Recovery Systems

There are several "traditional" technologies used to recover dissolved metals from process baths and rinsewater including ion-exchange, electrolytic recovery, reverse osmosis, and evaporative concentration. Each of these methods have specific advantages, which are being used by PCBF facilities in combination to achieve economical and efficient recovery. For example, electrolytic recovery is generally applicable to concentrated wastes, while ion-exchange is more often applied to dilute wastes. By first recovering metals electrolytically and then treating the resulting effluent via ion-exchange, a facility can achieve high recovery rates with much lower costs than could be achieved using either of these techniques alone. In the same way, dilute streams can be concentrated via ion-exchange, membranes or evaporation and then metals are recovered electrolytically. Regenerant from ion-exchange systems is often amenable to electrolytic recovery. Other recovery methods, such as freeze crystallization of copper sulfate are also possible.

On-site Regeneration and Treatment of Etchants

Certain etch chemistries such as cupric chloride and peroxy-sulfuric systems are amenable to regeneration or treatment on-site. Since most facilities use pattern plating and tin-lead etch resist, changing from ammoniacal etchants is impractical. Proprietary ammoniacal systems can also be regenerated, but have disadvantages of reduced etch rates and the need for anhydrous ammonia for regeneration. Hydroxide precipitation of spent cupric etchant is regulated under treatment by generator. (See Pacific Circuits letter in Appendix B.)

Pollution Prevention Opportunities: Off-Site Recovery and Reclamation

A majority of the wastes generated by PCBF facilities are treated on-site and discharged to local publicly owned treatment works (POTWs). The largest waste stream sent off-site for treatment and recovery is spent ammoniacal etchant. Approximately 1.6 million pounds per year of spent etchant laden with dissolved copper are sent off-site where copper and ammonium hydroxide are recovered.

Traditional etchant recovery methods have been subject to regulation by hazardous waste laws. New techniques for using spent etchant have been interpreted by Ecology to be outside of the purview of these regulations. In recent determinations, facilities which use etchant for chemical production or for low specification copper etching have been allowed to accept spent etchant from PCBF facilities as a product, without a hazardous waste manifest.

Etchant as Chemical Feedstock

The US Filter Corporation asked Ecology for a determination if spent etchant used for chemical feedstock for a manufacturing process would be subject to hazardous waste laws. Specifically, US Filter uses spent etchant to produce copper oxides, which are then used in the production of wood preservatives. The Department of Ecology determined that the etchant was being used as an effective substitute for a commercial product, and as a product it is not subject to RCRA regulations. (See US Filter correspondence in Appendix B.)

Etchant to Reclaim Copper

Spent ammoniacal etchant is also being used to reclaim copper from printed wafer board scrap. Proler, Inc. has asked Ecology to determine whether etchant used to etch more copper would remain a product until reclaimed. Ecology determined that since the etchant was being used for its intended purpose, it could be shipped as a product and not subject to hazardous waste laws. (See Proler correspondence in Appendix B.)

Several PCBF facilities are performing economic analyses on these off-site opportunities, incorporating total cost accounting methods. The results of these analyses will be compiled and distributed by Ecology.

Appendix A: P2 Opportunities Correlated to Opportunity Status[2]

The following is a list of all pollution prevention (P2) opportunities identified by the printed circuit board fabrication section in Washington State through the Pollution Prevention Planning process. This list provides a breakdown of the number of facilities that identified each opportunity by status category. The status categories indicate whether the pollution prevention opportunity was implemented prior to P2 planning (P), Implemented (1) after P2 planning, Selected (S) for implementation, selected for Further Study (F), or Rejected (R) after consideration.

P2 Opportunities Identified by PCB Manufacturers	**P**	**S**	**I**	**F**	**R**	**Tot.**
“Double treat” inner layer material	1	1		1		3
0.5 oz. Copper foil in place of 1 oz.	2					2
Acid distillation		1				1
Air agitation to improve rinsing	1					1
Alkaline etchants reclaimed	1			1		2
Alternative precipitants			1	1	1	3
Alternative process chemistry				1		1
Alternative solvent to acetone for mold cleaning				1		1
Alternative stripper chemistry	1			1	1	3
Aqueous cleaning				1		1
Aqueous conversion from solvent resists	1					1
Automate rinse water addition	4					4
Automation with air knives and squeegee rollers	1					1
Carbon test plating solutions	1					1
Carbon treatment to extend bath life	2					2
CFM - reposition process tanks to facilitate linear processing		1				1
Chemical recovery of decanted spent bright acid tin (Clarostan)				1		1
Chemical recovery of spent etch				1		1
Closed-loop via ion exchange	1					1
Combine corrosive wastes prior to treatment	1					1
Conversion from solvent to aqueous chemistry	1					1
Decrease bath temperature to reduce formaldehyde loss		1				1
Dissolved/suspended resist removed from stripper	1					1

P2 Opportunities Identified by PCB Manufacturers	P	S	I	F	R	Tot.
Drag-out reduction techniques	2	4	2			8
Electrolytic bath regeneration	1					1
Electrolytic rack strip					1	1
Electrolytic recovery on rinses, baths	4	2	1	2		9
Eliminate/reduce use of ferrous sulfate & sodium sulfide				1		1
Eliminate drilling fluids				1		1
Eliminate dumps of Cu-posit “Swell”		1				1
Eliminate halogenated organics				1		1
Eliminate sulfuric acid dip	1					1
Eliminate use of monoethanolamine in lubricants	1					1
Elimination of 1, 1, 1 TCA	2					2
Elimination of cyclohexane			1			1
Elimination of IPA from post clean rinse			1			1
Evaluate alternative technology to electroless plating				3		3
Filtration to extend bath life	3					3
Fuel blending waste solvent	1					1
High purity anodes to minimize contamination	1					1
HVLP s pray nozzles	1					1
Improve chemical storage to reduce waste	1					1
Improved maintenance	1	1	1			3
Improved pinch rollers				1		1
Improved rinse efficiency	1					1
Improved secondary containment		2				2
Increase freeboard on vapor degreasers	1					1
Install counter current rinses	5	1				6
Install final pH adjustment tank	3					3
Install flow restrictors to conserve water	3					3
Install ion exchange and electrolytic recovery	2	1		1		4
Install new wastewater treatment plant	1					1
Install ozone pretreatment of wastewater		1				1
Install pre-dip within process filtration	1					1
Install recovery rinses	2					2

P2 Opportunities Identified by PCB Manufacturers	P	S	I	F	R	Tot.
Install sludge dryer					2	2
Lower solder temperature					1	1
Maintain exit rollers and etchers			1			1
Mechanical agitation of parts of baths	1					1
Mechanical scrub to eliminate chemical preclean		1				1
Metals recovery via ion exchange				3		3
Minimize chemical purchases	1					1
Modify batch treatment recipes			1			1
New chemistry eliminating co-precipitation of metals		1				1
Optimize artwork layouts to minimize trim area		2				2
Optimize recovery rinses		1				1
Phosphoric acid microetch	1					1
Powder coat					1	1
Pre-mix polymer to improve flocculation	1					1
Pre-treat wastewater in staging sumps	3					3
Purge molds					1	1
Reclaim metals from sludge	2					2
Recycle ethylene glycol		1				1
Recycle flux					1	1
Recycle gold cyanide					1	1
Recycle lead trim		1				1
Recycle mylar				1		1
Recycle nitric rack strip	1					1
Recycle polycarbonate fixtures					1	1
Recycle scrap laminate				1		1
Recycle tin/lead strip	4					4
Reduce foil thickness to eliminate Sn/Pb and solder strip				1		1
Reduce sulfuric acid concentration		1		1		2
Reduce use of ferrous sulfate			1			1
Regenerate copper chloride		1				1
Regenerate ion exchange columns	1					1
Regenerate spent etchant on-site	1	1		3	2	7

P2 Opportunities Identified by PCB Manufacturers	P	S	I	F	R	Tot.
Return expired materials to vendor for reprocessing	1					1
S/PC to extend bath life	2	5	1			8
Segregate and treat influent wastestreams	1					1
Sodium borohydride precipitant	2					2
Solvent distillation	1					1
Substitute "211" bath in place of sulfuric	1					1
Substitute alcohol based coolant to inhibit rust					1	1
Substitute alternative chemistry (cupric, peroxide sulfuric)					1	1
Substitute alternative chemistry (MacDermid)				1		1
Substitute alternative chemistry (Sipley solvent, plasma)				1	1	2
Substitute alternative chemistry in place of DMP					1	1
Substitute alternative chemistry in place of formaldehyde				1		1
Substitute alternative chemistry/additive plate					1	1
Substitute alternative cleaner in place of alkaline cleaner		1				1
Substitute alternative cleaner in place of phosphoric acid		1				1
Substitute alternative process in place of nitric strip		2				2
Substitute for nitric solder strip					1	1
Substitute GR-1 screen cleaner in place of methylene chloride	1					1
Substitute air in place of freon TF propellant	1					1
Substitute matte in place of tine lead plating	1					1
Substitute microetch in place of nitric acid for rack cleaning			1			1
Substitute non-RCRA flux	1					1
Substitute panel print and etch in place of SnPb etch resist	1					1
Substitute propylene glycol in place of ethylene glycol						1
Substitute Shipley 748 in place of sulfuric acid			1		1	1
Substitute sodium borohydride in place of ferrous sulfate						1
Substitute sodium persulfate in place of peroxide/sulfuric					1	2
Substitute solder conditioner in place of solder brightener	1				2	1
Substitute solvent in place of toluene				1		1
Substitute SWT chemistry in place of ferrous sulfate						1
Substitute tin for tin/lead	2	2	1	1	1	6
Substitute toluene in place of methylene chloride	1					1

P2 Opportunities Identified by PCB Manufacturers	P	S	I	F	R	Tot.
Sulfuric acid pre-dip prior to acid copper	1					1
Tanks fitted with sloped lip cover to return drag-out to process	1					1
Treat spent carbon filters on-site		1				1
Treat spent phosphoric acid on-site				1		1
Two state resist stripping	1					1
Use alternative de-smear chemistry	1					1
Use alternative etchant					1	1
Use alternative to styrene in plastics		1				1
Use coated racks to reduce nitric rack strip	1	1	3	2	1	8
Use materials exchange	1					1
Use deionized make-up water to reduce bath contamination	1					1
Use less corrosive microetch	1				1	2
Use other inhibitor packages					1	1
Use spent baths for pH adjustment at WWTP	7					7
Use unlisted solvents				1		1
Vacuum distillation				1		1
Water borne paints				1		1
TOTAL	**105**	**41**	**17**	**40**	**28**	**231**

P - Prior to Planning
S - Selected
I - Implemented
F - Further Study
R - Rejected

[2]This table counts an opportunity once for each PCBF Sector facility that identified the opportunity although a single facility may have identified the same opportunity several times for different waste and substance targets that the opportunity could impact. Thus, a total of 231 opportunities are listed here, but PCBF Sector facilities identified a "total" of 408 opportunities.